

METHOD FOR DETECTING DELAYED DATA FRAMES IN A TRANSPORT FUNCTION

CROSS-REFERENCE TO RELATED APPLICATION

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This application is a continuation application of Application Serial No. 09/082,085, filed May 20, 1998, now allowed, entitled "Method for Detecting Delayed Data Frames in a Transport Function" which is a continuation-in-part of U.S. Application Serial No. 08/877,294, now U.S. Patent No. 6,011,796, filed 10 June 17, 1997.

BACKGROUND OF THE INVENTION

I. Field of the Invention

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The present invention pertains generally to the field of wireless communications, and more specifically to detecting delayed data frames in a transport function.

20 II. Background

The field of wireless communications has many applications including, e.g., cordless telephones, paging, wireless local loops, and satellite communication systems. A particularly important application is cellular 25 telephone systems for mobile subscribers. (As used herein, the term "cellular" systems encompasses both cellular and PCS frequencies.) Various over-the-air interfaces have been developed for such cellular telephone systems including, e.g., frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). In connection therewith, 30 various domestic and international standards have been established including, e.g., Advanced Mobile Phone Service (AMPS), Global System for Mobile (GSM),

and Interim Standard 95 (IS-95). In particular, IS-95 and its derivatives, such as IS-95A, IS-95B, ANSI J-STD-008, IS-99, IS-657, IS-707, etc. (often referred to collectively herein as IS-95), are promulgated by the Telecommunication Industry Association (TIA) and other well known standards bodies.

5 Cellular telephone systems configured in accordance with the use of the IS-95 standard employ CDMA signal processing techniques to provide highly efficient and robust cellular telephone service. An exemplary cellular telephone system configured substantially in accordance with the use of the IS-95 standard is described in U.S. Patent No. 5,103,459, which is assigned to the assignee of
10 the present invention and fully incorporated herein by reference. The aforesaid patent illustrates transmit, or forward-link, signal processing in a CDMA base station. Exemplary receive, or reverse-link, signal processing in a CDMA base station is described in U.S. Application Serial No. 08/987,172, now abandoned, filed December 9, 1997, entitled MULTICHANNEL DEMODULATOR, which is
15 assigned to the assignee of the present invention and fully incorporated herein by reference. In CDMA systems, over-the-air power control is a vital issue. An exemplary method of power control in a CDMA system is described in U.S. Patent No. 5,056,109, which is assigned to the assignee of the present invention and fully incorporated herein by reference.

20 A primary benefit of using a CDMA over-the-air interface is that communications are conducted over the same RF band. For example, each mobile subscriber unit (typically a cellular telephone) in a given cellular telephone system can communicate with the same base station by transmitting a reverse-link signal over the same 1.25 MHz of RF spectrum. Similarly, each base station
25 in such a system can communicate with mobile units by transmitting a forward-link signal over another 1.25 MHz of RF spectrum.

Transmitting signals over the same RF spectrum provides various benefits including, e.g., an increase in the frequency reuse of a cellular telephone system and the ability to conduct soft handoff between two or more base stations.
30 Increased frequency reuse allows a greater number of calls to be conducted over

a given amount of spectrum. Soft handoff is a robust method of transitioning a mobile unit from the coverage area of two or more base stations that involves simultaneously interfacing with two base stations. (In contrast, hard handoff involves terminating the interface with a first base station before establishing the 5 interface with a second base station.) An exemplary method of performing soft handoff is described in U.S. Patent No. 5,267,261, which is assigned to the assignee of the present invention and fully incorporated herein by reference.

Under the IS-99 and IS-707 standards (referred to hereinafter collectively 10 as IS-707), an IS-95-compliant communications system can provide both voice and data communications services. Data communications services allow digital data to be exchanged using a receiver and an RF interface to one or more transmitters. Examples of the type of digital data typically transmitted using the 15 IS-707 standard include computer files and electronic mail.

In accordance with both the IS-95 and IS-707 standards, the data 20 exchanged between a wireless terminal and a base station is processed in frames. To increase the likelihood that a frame will be successfully transmitted during a data transmission, IS-707 employs a radio link protocol (RLP) to track the frames transmitted successfully, and to perform frame retransmission when a frame is not transmitted successfully. Retransmission is performed up to three times in IS-707, and it is the responsibility of the higher layer protocols to take additional steps to ensure that the frame is successfully transmitted.

In order to track which frames have been transmitted successfully, IS-707 calls for an eight-bit sequence number to be included as a frame header in each 25 frame transmitted. The sequence number is incremented for each frame from 0 to 256 and then reset back to zero. An unsuccessfully transmitted frame is detected when a frame with an out-of-order sequence number is received, or an error is detected using CRC checksum information or other error detection methods. Once an unsuccessfully transmitted frame is detected, the receiver transmits a negative-acknowledgment message (NAK) to the transmit system 30 that includes the sequence number of the frame that was not received. The

transmit system then retransmits the frame including the sequence number as originally transmitted. If the retransmitted frame is not received successfully, a second negative-acknowledgment message is sent to the transmit system. The transmit system typically responds by notifying the controlling application or network layer of the failed transmission.

Under IS-95A and IS-707, frames are transmitted once every twenty milliseconds (ms). Thus, an eight-bit sequence number can track 256 frames transmitted over a five-second interval. Five seconds is typically sufficient to allow a failed frame transmission to be detected, and a retransmission to be performed, and therefore an eight-bit sequence number provides sufficient time for frame retransmission. Thus, retransmitted frames can be uniquely identified without ambiguity caused by a sequence "wrap-around" whereby the eight-bit sequence number repeats.

Since the original development of IS-95A and IS-707, however, additional protocols and standards have been proposed and developed that allow data to be transmitted at greater rates. Typically, these new protocols and standards use the same frame structure as IS-95A and IS-707 in order to maintain as much compatibility as possible with pre-existing systems and standards. Nevertheless, while maintaining compatibility with pre-existing standards and systems is desirable, the use of the same type of frame within these higher rate protocols and standards substantially increases the number of frames that are transmitted during a given period of time. For example, if the transmission rate is increased by a factor of four, the time required to transmit 256 frames is reduced to 1.25 seconds, rather than the five seconds required previously. A time period of 1.25 seconds is typically insufficient to allow a failed frame transmission to be detected, and a retransmission attempted, before the eight-bit sequence number repeats. Thus, the use of an eight-bit sequence number is insufficient to allow unique identification of frames for the time period necessary to perform the desired retransmission sequence.

A well-known protocol, the Radio Link Protocol (RLP), uses an eight-bit sequence counter included in frames sent over the air. The eight bits represent the least significant bits of a twelve-bit counter kept internally at both the receiver and the transmitter. The twelve-bit counter is updated based on the eight-bit numbers sent over the air. It stands to reason that delayed frames present a problem. If multiple frames are simultaneously sent from the transmitter but are delayed with respect to each other at the receiver, the twelve-bit counters will be incorrectly updated and the RLP will abort.

While the number of bits in the sequence number could be increased, such an increase would substantially alter the frame format and therefore violate the goal of maintaining substantial compatibility with previously existing systems and standards. Additionally, increasing the number of bits in the sequence number would waste available bandwidth. A conventional solution such as increasing the number of bits used to represent the sequence counter is therefore inadequate because it would introduce additional overhead per transmission and decrease of the net throughput of the transport service. Hence, it would be desirable to provide a method for extending the sequence number range without modifying the number of bits used for the sequence number. Such a method would advantageously be capable of interpreting an impossibly large number of missing data frames derived from the sequence number as a delayed frame, thereby increasing the throughput of the transport function. Thus, there is a need for an efficient method of detecting delayed frames in a transport function using a minimum number of bits.

25 SUMMARY OF THE INVENTION

The present invention is directed to an efficient method of detecting delayed frames in a transport function using a minimum number of bits. Accordingly, a method for detecting delayed data frames in a transport function 30 in which frames are sent from a transmitter to a receiver includes the steps of

comparing, for a received frame, a frame sequencing counter number with a predetermined threshold value, the frame sequencing counter number being derived from a header of the received frame, and detecting the received frame as a delayed frame if the frame sequencing counter number exceeds the threshold value. In one aspect of the invention, a data transmission system advantageously includes a transmitter, a receiver coupled to the transmitter via an interface for receiving data frames from the transmitter, and a protocol processing component housed in the receiver for comparing a frame sequencing counter number with a predetermined threshold value, the frame sequencing counter number being derived from headers of the data frames, the protocol processing component detecting a delayed data frame if the frame sequencing counter number exceeds the threshold value.

BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 is a block diagram of a cellular telephone system.

FIG. 2 is a schematic diagram of a transmitter and receiver.

FIG. 3 is a diagram of a frame buffer and resequencing buffer.

20 FIG. 4 is a flow chart illustrating the operation of a transmitter and a receiver during a communication.

FIG. 5 is a flow chart illustrating the operation of the receiver during the reception of a newly transmitted frame.

FIG. 6 is a flow chart illustrating the operation of the receiver during the reception of a retransmitted frame.

25 FIG. 7 is a message diagram illustrating the operation of the transmitter and the receiver during an exemplary communication.

FIG. 8 is a message diagram illustrating the operation of the transmitter and the receiver during an exemplary communication.

30 FIG. 9 is a flow chart illustrating the operation of the receiver in recognizing and processing delayed frames.

FIG. 10 is a functional diagram of a shift register used in the receiver to update a bit value specifying the next frame to be received.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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The embodiments described hereinbelow reside in a personal communication system operating in accordance with the use of CDMA signal processing techniques of the IS-707 and IS-95 standards. While the present invention is especially suited for use within such a communications system, it
10 should be understood that the present invention may be employed in various other types of communications systems that transmit data via frames or packets, including both wireless and wireline communication systems, and satellite-based communication systems. Additionally, throughout the description, various well-known systems are set forth in block form. This is done in order to avoid
15 unnecessarily obscuring the disclosure.

Various cellular systems for wireless telephone communication employ fixed base stations that communicate with mobile units via an over-the-air interface. Such cellular systems include, e.g., AMPS (analog), IS-54 (North American TDMA), GSM (Global System for Mobile communications TDMA), and
20 IS-95 (CDMA). In a preferred embodiment, the cellular system is a CDMA system.

As illustrated in FIG. 1, a CDMA wireless telephone system generally includes a plurality of mobile subscriber units **10**, a plurality of base stations **12**, a base station controller (BSC) **14**, and a mobile switching center (MSC) **16**. The
25 MSC **16** is configured to interface with a conventional public switch telephone network (PSTN) **18**. The MSC **16** is also configured to interface with the BSC **14**. The BSC **14** is coupled to each base station **12** via backhaul lines. The backhaul lines may be configured in accordance with any of several known interfaces including, e.g., E1/T1, ATM, or IP. It is to be understood that there
30 can be more than one BSC **14** in the system. Each base station **12**

advantageously includes at least one sector (not shown), each sector comprising an antenna pointed in a particular direction radially away from the base station

12. Alternatively, each sector may comprise two antennas for diversity reception.

Each base station **12** may advantageously be designed to support a plurality of

5 frequency assignments (each frequency assignment comprising 1.25 MHz of spectrum). The intersection of a sector and a frequency assignment may be referred to as a CDMA channel. The base stations **12** may also be known as

base station transceiver subsystems (BTSs) **12**. Alternatively, “base station” may be used in the industry to refer collectively to a BSC **14** and one or more

10 BTSs **12**, which BTSs **12** may also be denoted “cell sites” **12**. (Alternatively, individual sectors of a given BTS **12** may be referred to as cell sites.) The

mobile subscriber units **10** are typically cellular telephones **10**, and the cellular telephone system is advantageously a CDMA system configured for use in accordance with the IS-95 standard.

15 During typical operation of the cellular telephone system, the base stations **12** receive sets of reverse-link signals from sets of mobile units **10**. The mobile units **10** are conducting telephone calls or other communications. Each reverse-link signal received by a given base station **12** is processed within that base station **12**. The resulting data is forwarded to the BSC **14**. The BSC **14**

20 provides call resource allocation and mobility management functionality including the orchestration of soft handoffs between base stations **12**. The BSC **14** also routes the received data to the MSC **16**, which provides additional routing services for interface with the PSTN **18**. Similarly, the PSTN **18** interfaces with the MSC **16**, and the MSC **16** interfaces with the BSC **14**, which in turn controls

25 the base stations **12** to transmit sets of forward-link signals to sets of mobile units **10**.

In the embodiments described below, an algorithm serves to map an eight-bit sequencing number for counting frames sent over the air into a twelve-bit sequencing number in accordance with the Radio Link Protocol (RLP), a

30 protocol that is known in the art. The algorithm is advantageously carried out

with RLP software instructions and a microprocessor. In one embodiment, an RLP component may reside in a base station 12. Alternatively, the RLP component may reside in a BSC 14. Those of skill in the art would appreciate that the RLP algorithm may be used not only in a BSC 14 or a base station 12, 5 but could be used in any transport layer in which multiple data frames are received in a particular processing period.

In FIG. 2, two communication systems configured in accordance with an exemplary embodiment are illustrated in block form. The higher rate communication is being conducted from transmitter 50 to receiver 52. In an 10 exemplary configuration, transmitter 50 is located in a base station 12 and receiver 52 is in a wireless terminal 10; however, the locations may be reversed. Within transmitter 50, control system 54 receives data frames from input/output (I/O) 56 and provides that data to encoder 58. Encoder 58 performs convolutional encoding, generating code symbols that are received by digital modulator 60. Digital modulator 60 performs direct sequence modulation on the 15 code symbols with one or more binary channel codes and one or more binary spreading codes, yielding chipped symbols that are received by radio frequency (RF) transmitter 62. The chipped symbols are upconverted to the carrier frequency band by RF transmitter 62 and transmitted from antenna system 64 via diplexer 66.

Various methods and apparatuses for performing the digital modulation and RF upconversion can be employed. A set of particularly useful methods and apparatus are described in U.S. Patent Nos. 6,005,855, entitled METHOD AND APPARATUS FOR PROVIDING VARIABLE RATE DATA IN A 25 COMMUNICATIONS SYSTEM USING STATISTICAL MULTIPLEXING, filed April 28, 1995; 5,777,990, entitled METHOD AND APPARATUS FOR PROVIDING VARIABLE RATE DATA IN A COMMUNICATIONS SYSTEMS USING NON-ORTHOGONAL OVERFLOW CHANNELS, filed February 28, 1995; and 6,173,005, entitled HIGH DATA RATE SUPPLEMENTAL CHANNEL 30 FOR CDMA TELECOMMUNICATIONS SYSTEM, filed January 15, 1997; each

of which is assigned to the assignee of the present invention and fully incorporated herein by reference. It should be understood that some of the above-referenced patent applications are directed to the forward link, and are therefore more suited for use with the transmitter **50**, while others are directed to
5 the reverse link, and are therefore more suited for use with the receiver **52**.

In an exemplary embodiment, the data transmitted from antenna system **64** is formatted in accordance with frames **70** that include an eight-bit sequence field (SEQ number) **72**, a retransmit flag **74**, and a data field **76**. A frame **70** may include other fields that are not shown because they are not particularly relevant
10 to the present invention. In a preferred embodiment, the frames are formatted substantially in accordance with the frame structures defined in the IS-707 standard, with the addition of retransmit flag **74**.

To provide data frames to encoder **58** in an orderly manner, control system **54** stores the frames within frame buffer **55** and updates an index value **L_V(S)**. Frame buffer **55** and index value **L_V(S)** are preferably stored within a memory system. In a preferred embodiment, index value **L_V(S)** is a twelve-bit sequence number that is incremented after the transmission of each frame as described in greater detail below. The least significant eight bits of index value **L_V(S)** are placed in the sequence field of a frame **72**.

20 Within receiver **52**, RF receiver **80** downconverts and digitizes the RF signals on which frame **70** is transmitted using antenna system **82** and diplexer **84**. Digital demodulator **86** demodulates the downconverted, or “baseband,” signals using the necessary binary codes, generating soft decision data that is received by decoder **88**. Decoder **88** performs maximum likelihood trellis, or
25 Viterbi, decoding, yielding hard decision data **90** that is provided to controller **91**.

Controller **91** reforms frame **70** using hard decision data **90** and determines whether the frame has been received in sequence relative to the frames that have already been received using the SEQ number, index variable **L_V(N)**, and **L_V(R)**, as well as resequencing buffer **92** and NAK list **94** as
30 described in further detail below.

If controller 91 determines that the frame has been received out of sequence relative to the frames that have already been received, or if the frame is received in error, it generates a negative-acknowledgment (NAK) message that is received by encoder 95. Encoder 95 performs convolutional encoding to 5 generate code symbols that are direct sequence spread spectrum modulated by digital modulator 97, preferably in accordance with the IS-95 reverse link, and the chipped symbols are upconverted by RF transmit system 98 and transmitted as NAK 83 from antenna system 82 via diplexer 84. The L_SEQ for the NAKed frame is stored within NAK list 94.

10 Referring again to transmitter 50, RF receiver 67 receives the RF signal via antenna system 64 and diplexer 66. RF receiver 67 downconverts and digitizes the RF signal, yielding samples that are demodulated using digital demodulator 68. Decoder 69 decodes the soft decision data from digital demodulator 68, and control system 54 receives the hard decision data from 15 decoder 69, thereby detecting the NAK 83 from receiver 52 contained in the hard decision data.

Control system 54 receives NAK 83 and retrieves the NAKed frame from 20 transmit buffer 55. The retrieved frames are retransmitted in accordance with the original transmission as described above (including the original sequence number).

The configuration of frame buffer 55, resequencing buffer 92, and indexes L_V(S), L_V(N), and L_V(R), when used in accordance with one embodiment, are illustrated in FIG. 3. Within the transmit frame buffer 55, frames already transmitted once are shaded, and frames to be transmitted are clear. In a 25 preferred embodiment, indexes L_V(S), L_V(N), and L_V(R) are twelve-bit numbers. Index L_V(S) is set to the sequence number of the next frame to be transmitted. When the frame is actually transmitted, the eight-bit SEQ number of the frame is set to the eight least significant bits of index L_V(S).

Within resequencing buffer 92, index L_V(R) is set to the twelve-bit 30 sequence of the next new frame expected. Index L_V(N) is set to the twelve-bit

sequence of the next frame needed for sequential delivery, or for which processing is still pending. When a predetermined number of NAKs **83** have been sent without receipt of the corresponding frame, attempted processing of the frame is terminated and the data with the missing frame is passed to the
5 higher layer protocols such as, e.g., the transport layer. As shown, NAKed frames **96a - c** can be received with sequence numbers between $L_V(N)$ and $(L_V(R)-1) \text{ MOD } 4096$, inclusively.

In FIG. 4, a flow diagram illustrates the operation of the transmitter **50** and receiver **52** during a communication performed in accordance with one embodiment. The transmission begins at the transmitter at step **100**, with reception at the receiver occurring at step **101**. At step **102**, initialization is performed, during which index $L_V(S)$ is set to zero within transmitter **50** and $L_V(R)$ is set to zero within receiver **52**.

At step **108**, the transmitter **50** transmits a frame (indicated by the dashed line) when data is available for transmission, with the SEQ number of the frame being set to the eight least significant bits of index $L_V(S)$, and being referred to as $V(S)$. Additionally, the retransmit flag is set to zero to indicate that the frame is a newly transmitted frame. At step **112**, index $L_V(S)$ is incremented MOD 4096, and at step **113** the transmitter performs receive processing for any NAK message transmitted from receiver **52**. In one embodiment, when no data is available, “idle” frames having the current SEQ number may be sent repeatedly until data becomes available (idle transmissions not shown).

At step **130** the transmitter **50** determines if a NAK **83** has been received or is pending, , and if so the NAKed frames are retrieved from the transmit buffer
25 using the long sequence number contained in the NAK message and retransmitted at step **132** with the original SEQ number and the retransmit field set to one. Once the frame is retransmitted the pending or received NAK **83** is cleared and processing then continues at step **113**.

If a NAK message has not been received or is not pending, the transmitter
30 returns to step **108** and the processing continues.

- Within receiver 52, the processing begins at step 101, and at step 106 $L_V(S)$ is received from transmitter 50. At step 110, receiver 52 receives any frames transmitted from transmitter 50 at either step 108 (new transmission), or at step 132 (retransmission), and at step 114 receiver 52 examines the status of 5 the retransmit flag of the frame to determine if the received frame is a retransmitted frame or a new frame. If the frame is a retransmitted frame, retransmit processing is performed at step 116, and then the receiver returns to step 110. If the frame is not a retransmitted frame, first transmit processing of the frame is performed at step 120, and then step 110 is performed again.
- 10 In FIG. 5, a flow chart illustrates the operation of receiver 52 when processing the first transmission of a frame during step 120 of FIG. 4 in accordance with one embodiment. The first transmission processing begins at step 150, and at step 152 L_SEQ is set according to the following equation:

$$15 \quad L_SEQ = \{L_V(R) + [256 + SEQ - V(R)] MOD 256\} MOD 4096, \quad (1)$$

where $V(R)$ is the eight least significant bits of $L_V(R)$ and SEQ is the sequence number contained in the SEQ field of the frame being processed. At step 154 it is determined whether L_SEQ is less than $L_V(N)$, or that the frame has been 20 stored in the resequencing buffer 92. If so, the frame is discarded at step 156 and the receive system returns from first transmission processing at step 157. As noted above, $L_V(N)$ is set to the next frame needed for sequential delivery of the data.

If L_SEQ is not less than $L_V(N)$ and the frame has not been stored in the 25 resequencing buffer 92, it is further determined at step 158 whether L_SEQ is greater than or equal to $L_V(N)$ and less than $L_V(R)$, and whether the frame has been not stored in the resequencing buffer 92. If so, the frame is discarded at step 156 and the receive system returns from first transmission processing at step 157. Otherwise, it is further determined at step 160 whether L_SEQ equals 30 $L_V(R)$ and therefore is the next frame needed for sequential delivery $L_V(R)$.

If L_SEQ does not equal $L_V(R)$, an out-of-order frame has been received, and the frame is stored in the resequencing buffer **92** at step **162**, and $L_V(R)$ is set to L_SEQ at step **164**. At step **166**, the receive system transmits one or more NAK messages requesting retransmission of all unreceived frames
5 from $L_V(N)$ to $(L_V(R) - 1) \text{ MOD } 4096$, inclusive. The receive system then returns from the first transmission processing at step **176**.

If, at step **160**, it is determined that L_SEQ equals $L_V(R)$, the frame has been received in order, causing it to further be determined at step **170** whether $L_V(N)$ equals $L_V(R)$, which indicates that no NAKed frames are outstanding. If
10 $L_V(N)$ equals $L_V(R)$, $L_N(N)$ and $L_V(R)$ are incremented MOD 4096 at step **172**. The data frame is delivered to the higher layer protocol at step **174**, and the receiver **52** returns from first transmit processing at step **176**.

If it is determined at step **160** that $L_V(N)$ does not equals $L_V(R)$, and therefore that NAKed frames remain outstanding, $L_V(R)$ is incremented MOD 4096 at step **178**, and at step **180** the frame is stored in the resequencing buffer **92**. The receiver **52** then returns from the first frame transmit processing at step **176**.

In FIG. 6, a flow diagram illustrates the operation of the receiver **52** during step **116** when a retransmitted frame is received in accordance with one embodiment. The processing of the retransmitted frame begins at step **200**, and at step **202** the SEQ field in the received frame is used as the key to look up an L_SEQ associated with the SEQ in the NAK list **94** (see FIG. 2). At step **204** it is determined whether the L_SEQ is less than $L_V(N)$, or whether the frame has already been stored in the resequencing buffer **92**. If so, the frame is discarded
20 at step **206**, and the receiver **52** returns from retransmit processing at step **208**.

If L_SEQ is not less than $L_V(N)$, and the frame has not been stored in the resequencing buffer **92**, it is further determined at step **210** whether L_SEQ is greater than or equal to $L_V(N)$ and less than $L_V(R)$, and if the frame has not been stored in the resequencing buffer **92**. If so, the frame is stored in the

resequencing buffer **92** at step **212** before step **214** is performed. Otherwise, step **214** is performed.

At step **214**, it is determined whether L_SEQ is equal to $L_V(N)$, and if not, the frame is discarded at step **216** because the retransmitted frame has a sequence number that is higher than the next new frame expected, and therefore an error has occurred. Once the frame has been discarded, receiver **52** returns from retransmitted frame processing at step **208**.

If L_SEQ equals $L_V(N)$, the data in all the contiguous frames formed by the addition of the retransmitted frame being processed from $L_V(N)$ upward are delivered to the next higher processing layer at step **218**, and the delivered frames are removed from the resequencing buffer **92** at step **220**. At step **222** $L_V(N)$ is set to $LAST+1$, where $LAST$ is the long sequence number (L_SEQ) of the last frame delivered to the higher layer at step **218**. At step **224** the frame is removed from the NAK list and the receiver **52** returns from processing the retransmitted frame at step **226**.

In FIG. 7, a message diagram illustrates the messages transmitted during an exemplary communication performed in accordance with one embodiment. Transmitter **50** is shown on the left, and receiver **52** is shown on the right. Transmitter **50** maintains index $L_V(S)$, and frames are transmitted with value $V(S)$ in the sequence field, where $V(S)$ is the eight least significant bits of $L_V(S)$. At the receiver **52** the NAK list after each transmission is shown. All numbers are shown in hexadecimal.

The first frame **230** is transmitted when index $L_V(S)$ is equal to 0x2FE, and therefore with a SEQ number of 0xFE. After the transmission of frame **230**, index $L_V(S)$ is incremented to 0x2FF and frame **232** is transmitted with a SEQ number of 0xFF. Both frames **230** and **232** are received successfully by receiver **52**, causing index $L_V(R)$ to increment twice from 0x2FE to 0x300.

Frame **234** is transmitted with a SEQ number of 0x00 and is not successfully received by receiver **52**. $L_V(S)$ is then incremented to 0x301, and

frame **236** is transmitted with a SEQ number of 0x01 and is received successfully by receiver **52**.

Upon receipt of frame **236**, receiver **52** detects the out-of-order sequence number because frame **234** was not received. In response, receiver **52** generates NAK message **240** containing the full twelve-bit index L_V(R) for the unreceived frame 0x300. Additionally, receiver **52** updates the NAK list **94** to indicate that a NAK **83** has been transmitted for a frame with SEQ number 0x00 and L_SEQ number 0x300. Also, receiver **52** starts a NAK timer, which tracks the time that has expired since the transmission of NAK message **240**.

During the transmission of NAK message **240**, transmitter **50** transmits another frame **238** with a SEQ number of 0x02, which is received successfully by receiver **52**. Upon receipt of NAK message **240**, transmitter **50** generates retransmitted frame **242** having SEQ number 0x00 and the retransmit flag **74** (see FIG. 2) is set to one. Upon receipt of retransmitted frame **242**, receiver **52** detects the retransmission bit and matches the SEQ number with the SEQ number in NAK list **94**.

Once the match is made, retransmitted frame **242** is placed within the resequencing buffer **92** (see FIG. 2) and the entry within NAK list **94** is removed. Frames **244** and **246** are then transmitted and received in normal fashion.

In FIG. 8, a message diagram further illustrates the operation of transmitter **50** and receiver **52** during a transmission in which the sequence number “wraps-around,” when performed in accordance with one embodiment. Frames **240a** and **240b** are transmitted with SEQ numbers 0xFE (all numbers are in hexadecimal) and 0xFF, respectively, which correspond to values of 0x2FE and 0x2FF for index L_V(S), and are successfully received by receiver **52**, causing L_V(R) to be incremented from 0x2FE to 0x300.

Frame **240c** includes SEQ number 0x00 but is not successfully received by receiver **52**. Frame **240d** includes SEQ number 0x01 and is received properly by receiver **52**. Upon receipt of frame **240d**, receiver **52** detects that the SEQ number is greater than the eight least significant bits of L_V(R), and therefore

that a frame has been received out of order. In response, receiver **52** updates L_V(R) to 0x302, which corresponds to the next expected frame, and places the SEQ number of the unreceived frame into NAK list **94**. Additionally, receiver **52** transmits NAK **241** containing the complete L_SEQ number 0x300 of the frame
5 that was not received, and initiates a timer that tracks the amount of time that has expired since the transmission of the NAK **241**. As shown in FIG. 8, however, NAK **241** is not received successfully by transmitter **50**.

Transmitter **50** continues to transmit frames as shown, including frames **240e - 240j**, all of which are successfully received by receiver **52**. During the
10 transmission of frames **240e - 240j**, index L_V(S) changes from 0x302 to 0x400, causing a wrap-around in eight least significant bits, and therefore in the SEQ number contained in the frames.

Frame **240k** is transmitted with SEQ number 0x01 and is not received successfully by receiver **52**. Frame **240l** is transmitted with SEQ number 0x02 and is received successfully by receiver **52**. Upon receipt of frame **240l**, receiver **52** detects an out-of-order transmission, and responds by transmitting NAK **243** containing sequence value 0x401 and by adding sequence number 0x401 to NAK list **94**. Additionally, at this time the timer for NAK **241** expires, causing a second NAK **245** containing sequence value 0x300 to be transmitted to
15 transmitter **50**. Thus, a second NAK is transmitted for frame **240c**. Additionally, receiver **52** sets L_V(R) to the next expected sequence number 0x403. It should be noted that the sequence numbers transmitted in NAKs **243** and **245** could be transmitted in a single NAK message.

Transmitter **50** responds to NAKs **243** and **245** by transmitting
20 retransmitted frame **242a** containing the data from frame **240k**, and retransmitted frame **242b** containing the data from frame **240c**. Upon receipt of retransmission frame **242a**, receiver **52** identifies the frame as a retransmitted frame based on the status of retransmit flag **74** (see FIG. 2). Once the frame is identified as a retransmitted frame, receiver **52** performs a lookup within NAK list

94, using the SEQ number, and determines which frame has been retransmitted. Retransmitted frame 242a is then placed in the appropriate location within resequencing buffer 92 (see FIG. 2), and the corresponding entry is removed from NAK list 94.

5 Upon receipt of retransmission frame 242b, receiver 52 also identifies the type of frame and performs a lookup within NAK list 94. When the identity of the frame is determined, it is placed within the resequencing buffer 92 (see FIG. 2), and the corresponding entry is removed from NAK list 94. Transmitter 50 then transmits frame 240m having sequence number 0x03, which is successfully
10 received by receiver 52. At this point, NAK list 94 is empty.

As should be evident from the transmission shown in FIG. 8, marking frames as either “new” or “retransmitted” allows the receiver 52 to properly process both new and retransmitted frames that have the same SEQ numbers even when wrap-around of the sequence number occurs during a
15 retransmission. This is possible because a retransmitted frame with the same SEQ number as a newly transmitted frame can be distinguished by the retransmit flag. Thus, a greater number of frames may be processed using an eight-bit sequence number, which supports significantly higher data rates while maintaining substantial computability with pre-existing standards.

20 In FIG. 9, a flow chart illustrates the operation of the receiver 52 in recognizing and processing delayed frames in accordance with one embodiment. A delayed frame may be defined as an RLP frame that is transmitted at the same time on the over-the-air interface with a group, or bundle, of other RLP frames, but has experienced a significantly different delay (e.g., due to a different
25 path length) on its way to the receiver 52. In accordance with the IS-707-A standard and RLP, a known protocol for retransmission of data frames, frames are sent over the air in twenty-millisecond (ms) intervals. If the difference in the delay is more than twenty ms, the delayed frame will be received in one of the following twenty-ms processing intervals identified in IS-707-A. If not detected
30 as a delayed frame, a delayed RLP frame may cause an RLP reset.

Equation (1), described above in connection with FIGS. 4-6, presents a method for mapping the eight-bit SEQ number (which is transmitted as a frame header over the air) into a twelve-bit L_SEQ number at the receiver 52 to keep track of frame sequence. If, by way of example, frames 1, 2, and 4 of a four-frame bundle are received within the same twenty-ms time interval, but frame 3 is delayed and is received in the following twenty-ms time interval, equation (1) yields the following value for L_SEQ:

$$\begin{aligned} \text{L_SEQ} &= \{L_V(R) + [256 + \text{SEQ} - V(R)] \text{ MOD } 256\} \text{ MOD } 4096 \\ 10 &= \{5 + [256 + 3 - 5] \text{ MOD } 256\} \text{ MOD } 4096 \\ &= 5 + 254, \end{aligned}$$

which indicates that 254 frames are missing. Clearly, this is not the correct interpretation because it is impossible to miss 254 frames within a twenty-ms time interval. In the embodiment depicted in FIG. 9, an RLP algorithm advantageously categorizes such a frame as a delayed frame at the receiver 52.

In the embodiment of FIG. 9, the value D denotes the maximum difference in the arrival time for RLP frames that are transmitted in the same twenty-ms time interval on the over-the-air interface. D is expressed in units of twenty-ms time intervals and is typically zero, one, or two. The number $V(R)_{T-D}$ denotes the value of $V(R)$ at a time of $D \times 20$ ms ago. The value N_{max} denotes the maximum number of frames that can be sent in one twenty-ms time interval. N_{max} may be eight in a particular embodiment. In another embodiment, N_{max} may be four.

25 In step 300, a frame is received at the receiver 52. The algorithm then proceeds to step 302 and determines whether the frame is a new frame. If the frame is a new frame, the algorithm proceeds to step 304. If the frame is not a new frame, the algorithm proceeds to step 306 to process the frame as a retransmitted frame. In step 306, the algorithm processes the frame as a

retransmitted frame via a table, as described above. The algorithm then returns to step **300** and receives the next frame.

In step **304**, the algorithm determines whether $L_V(R)$ has been updated within the past $D \times 20$ ms. $L_V(R)$ is the twelve-bit value of $V(R)$, which points to

5 the next frame the RLP algorithm expects to receive in the receive buffer. If $L_V(R)$ has not been updated in the past $D \times 20$ ms, equation (1) will not yield an impossibly large number of missing frames, so the algorithm proceeds to step **306**, processing the frame as a retransmitted frame. If $L_V(R)$ has been updated within the past $D \times 20$ ms, there is a possibility that the new frame is a delayed

10 frame, and the algorithm proceeds to step **308**.

In step **308**, the algorithm commences new frame processing by computing the value $H = (256 + SEQ - V(R)_{T-D}) \text{ MOD } 256$. The algorithm then proceeds to step **310**. In step **310**, the algorithm determines whether H is greater than $N_{\max} \times D$.

If H is greater than $N_{\max} \times D$, the algorithm detects the frame as a delayed frame and proceeds to step **306**, advantageously processing the detected delayed frame as a retransmitted frame. Those of skill in the art would understand that because L_SEQ equals $[L_V(R) + H] \text{ MOD } 4096$ (see equation (1)), checking if H is greater than the threshold value $N_{\max} \times D$ (which represents the maximum number of frames that could be missing) simply amounts to comparing L_SEQ with a threshold value. If L_SEQ is found to exceed the threshold value, a delayed frame is detected and processed accordingly.

Those of skill in the art would likewise appreciate that in an alternate embodiment not employing RLP frames, the delayed frame need not necessarily be processed as a retransmitted frame, but might instead be processed in some other manner. If H is not greater than $N_{\max} \times D$, the algorithm proceeds to step **312** and processes the frame as a new frame via equation (1), as described above. The algorithm then returns to step **300** and receives the next frame.

In one embodiment, illustrated in FIG. 10, a shift register **400** in the receiver **52** (see FIG. 2) may advantageously be used to keep track of the value

of $V(R)_{T-D}$. The shift register **400** must have $D+1$ stages (i.e., the shift register **400** must have a number of bits equal to $(D+1)$ multiplied by the bit length of $V(R)$). The bit value $V(R)$ is put into the shift register **400** and, as shown, the shift register **400** is shifted every twenty ms to update $V(R)_{T-D}$. If $L_V(R)$ (or, 5 equivalently, $V(R)$) was not updated within the past twenty-ms time interval, a special value predetermined to denote a “null” symbol is advantageously placed in the shift register **400** to represent that no change took place.

Preferred embodiments of the present invention have thus been shown and described. It would be apparent to one of ordinary skill in the art, however, 10 that numerous alterations may be made to the embodiments herein disclosed without departing from the spirit or scope of the invention. Therefore, the present invention is not to be limited except in accordance with the following claims.

WE CLAIM:

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